

Ultrafiltration for Treatment of Natural Rubber Effluent Using Gas Sparging Technique

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Physical and chemical properties of natural rubber effluent have been influenced by large amounts of non-rubber compounds and chemicals, which can seriously damage or kill the natural flora and fauna of the waters when the effluent is discharged untreated. This study presents the application of membrane technology for the treatment of natural rubber processing effluent that involves gas injection technique. During the experiments, permeate was collected and analysed for several characteristics such as total solids (TS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total nitrogen and ammoniacal nitrogen (NH₃-N). The results showed that the use of gas sparging technique enhanced total permeate flux in the range 8.3% and 145.3% compared to the non-gas sparging technique. In terms of permeate quality, reductions achieved for TS, COD, BOD, total nitrogen and NH₃-N were 95%, 67%, 77%, 51%, 74%, respectively. For the non-gas sparging technique, permeate flux declined sharply with time due to the accumulation of foulant on the membrane surface. However both conditions showed increase of total permeate flux with transmembrane pressure and feed flow-rate.

Key words: natural rubber; effluent; treatment; crossflow ultrafiltration; gas sparging; TS; COD; BOD; total nitrogen; NH₃-N

Malaysia is a major producer of agricultural products. Although processing of agricultural products plays an important role in the economic development of Malaysia, it has also been identified as one of the major sources of pollution in the country. One such agricultural product is natural rubber processing effluent which can seriously damage or kill the natural flora and fauna of the waters when the effluent is discharged untreated. Currently most of the natural rubber effluent treatment in Malaysia uses the anaerobic/facultative ponding system. This system is popular due to its simplicity in operation and low operating cost. Although this

system is effective in treating most of the pollutants from natural rubber effluent, this system needs ample land for its construction and is not suitable for factories in urban areas because of offensive smell emission especially when it rains¹.

There is an emerging trend towards the use of other technologies such as membrane technology to enhance treatment process performance²⁻⁴. Nowadays, industries avoid the use of dead-end filtration mode which causes build up of debris on the membrane surface, thus effecting a reduction in fluid permeation.

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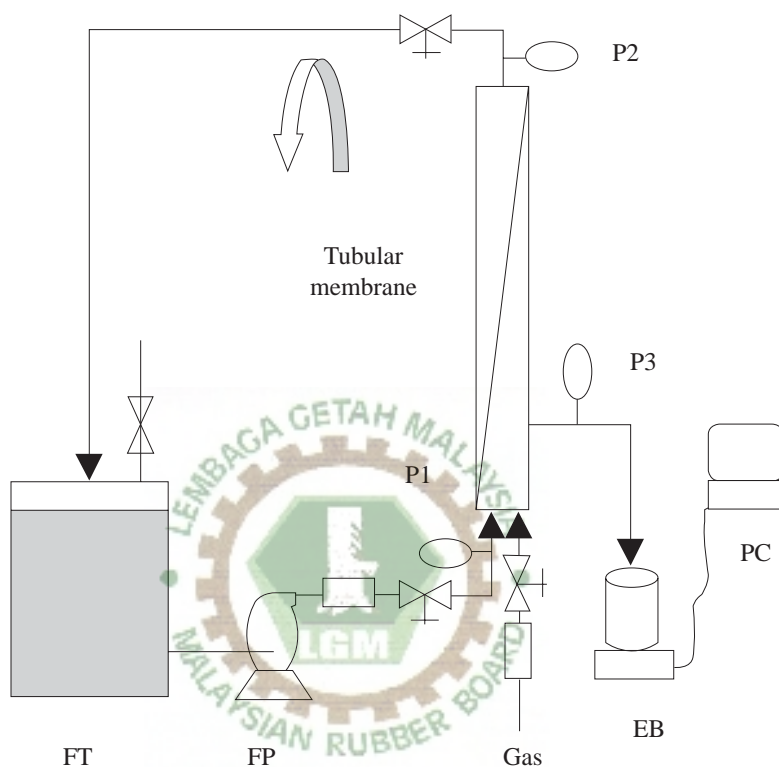
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Conversely, crossflow filtration employs tangential flow across the membrane surface^{5,6}. Recently, the use of membrane filtration that involves gas sparging technique is being studied for the treatment of natural rubber effluent^{7,8}. The aim of this study is to investigate the effects of operating conditions on the performance of ultrafiltration for the treatment of natural rubber effluent using gas sparging technique.

MATERIALS AND METHODS

Experimental Set-up

The schematic diagram of crossflow ultrafiltration with gas sparging technique system is shown in *Figure 1*. All experiments were carried out at room temperature. A pilot scale system using a PVDF vertical tubular membrane (MWCO 100 000) was installed for



FT: Feed tank; FP: Feed pump; EB: Electronic balance; P1: Inlet pressure; P2: Outlet pressure; P3: Permeate pressure; PC: Personal computer

Figure 1. Schematic diagram (semi-pilot scale) of the upward crossflow ultrafiltration system.

the experimental set-up. It had an internal diameter of 12.5 mm; length of 1.2 m; and effective surface area of 0.047 m². The natural rubber effluent solution was driven from a feed tank by a gear pump and circulated through the membrane module with upward flow. The gas was directly injected to the inlet (bottom) of the membrane through a solenoid valve. Permeate was weighed using an electronic balance, the mass was recorded every five seconds and then recycled back to the feed tank to maintain a constant feed concentration. After each experimental run, the membrane was cleaned immediately with 1% sodium hydroxide and then flushed with distilled water. After cleaning, the flux was checked to ensure that the intrinsic membrane resistance had recovered to its original value.

Operational Parameters

In order to evaluate the stability and capability of membrane processes, experiments were carried out at different operational conditions and parameters. The range of transmembrane pressure (TMP) was varied from 7.5 psig to 13 psig, flow rate gas sparging of 0 mL/min – 500 mL/min and liquid feed flowrate between 1000 mL/min and 1600 mL/min. All experiments were carried out at room temperature. Each experiment was run for 4 h with interval of 30 min for sampling under both gas sparged and non-gas sparged conditions.

Sampling and Analytical Methods

Skim natural rubber latex serum derived from coagulation of skim latex was obtained from a factory. Due to the milky nature of the skim latex serum, it was necessary to store it overnight before use. Effluent sample and permeate was collected to be analysed for pH, total solid (TS), chemical oxygen demand

(COD), biochemical oxygen demand (BOD), total nitrogen and ammonia nitrogen (NH₃-N). The analyses were performed in accordance with procedures described in the standard methods for examination of water and waste water⁹.

RESULTS AND DISCUSSIONS

Permeate Quality Achieved

The characteristics of effluent after treatment which involved gas sparging and non-gas sparging techniques are shown in *Tables 1* and *2*.

Both tables showed that characteristics of the permeate quality were not distinctly different, probably due to use of the same material and molecular weight cut-off of the membrane. However the total nitrogen content in permeate under gas sparging condition was higher than under non-gas sparging condition. This is probably due to some of the nitrogen gas being soluble in the feed stream during the experimental run. Consequently, the dissolved total nitrogen in permeate under gas sparging was higher than non-gas sparging condition.

Effect of Gas Sparging on Permeate Flux

Permeate flux with time at a constant feed flow-rate (1400 mL/min) and different gas sparging flow rate for 240 min is given in *Figure 2*. The effect of the flow rate of gas sparging on permeate flux at different transmembrane pressure for 240 min is shown in *Figure 3*. Both graphs showed that permeate fluxes increased significantly for different flow rate of gas sparging and transmembrane pressure. In *Figure 3* it can be seen that permeate flux is found to decrease with time as

TABLE 1. CHARACTERISTICS OF PERMEATE AFTER ULTRAFILTRATION UNDER GAS SPARGING CONDITION

Parameters	Feed	Permeate	Removal (%)
pH	3.75	4.46	+16
Total solid	7100	370	95
COD	3998	1332	67
BOD ₅	3642	853	77
Total nitrogen	596	295	51
NH ₄ -N	435	115	74

(All values except pH are expressed in mg/L)

TABLE 2. CHARACTERISTICS OF PERMEATE AFTER ULTRAFILTRATION UNDER NON-GAS SPARGING CONDITION

Parameters	Feed	Permeate	Removal (%)
pH	3.75	4.42	+15
Total solid	7100	300	96
COD	3998	1337	67
BOD ₅	3642	1012	72
Total Nitrogen	596	240	60
NH ₄ -N	435	110	75

(All values except pH are expressed in mg/L)

the retained particles accumulate on the membrane surface and start to show the effect of fouling. Accumulation of cells, cell debris, or other rejected particles on the membrane surface occurs as external fouling or cake formation and is usually reversible. From both figures it is shown that the use of gas sparging technique can enhance permeate flux due to gas sparging technique and can also disrupt the cake-layer formation on the membrane surface, as a consequence, some of the cell debris or foulant is swept away from the membrane surface.

The use of gas sparging technique also promotes turbulence in the feed stream

thus reducing cake-layer formation on the membrane surface. Results in permeate flux that are obtained are also higher due to the increase in turbulence in the feed stream. From all the operating conditions that were applied as mentioned above, the use of gas sparging technique in upward cross flow when compared with the normal or conventional cross flow under non-gas sparging operation show a permeate flux increase in the range of 8.3% to 145.3%.

Figure 3 shows that the highest permeate flux was obtained at flow rate of gas sparging of 500 mL/min and at transmembrane pressure of 13 psig. *Figure 4* also shows that further

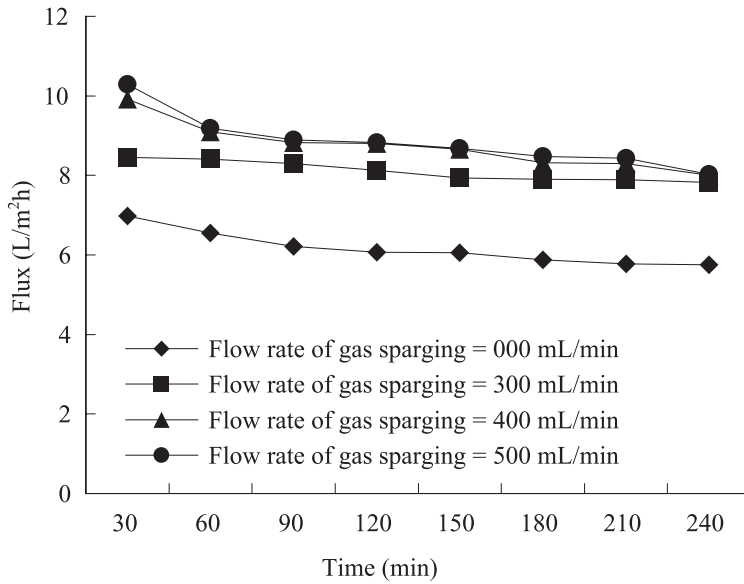


Figure 2. Permeate flux with time at different flow rates of gas sparging and a feed flow rate of 1400 mL/min and TMP 13 psig.

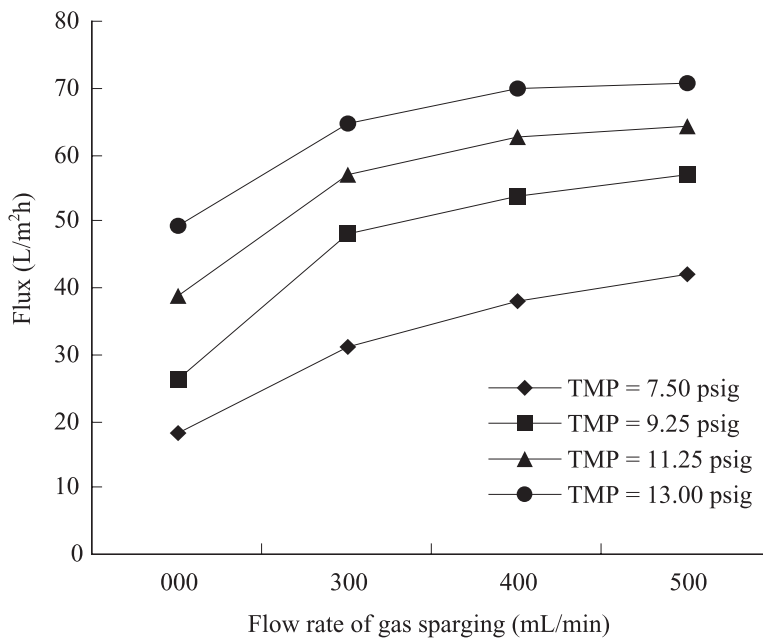


Figure 3. Effect of gas sparging flow-rate on permeate flux at feed flow-rate of 1400 mL/min and at different transmembrane pressures (TMP) for 240 min.

increase in flow rate of gas sparging did not result in further increase of total permeate flux. It happened due to the increase in flow rate of gas sparging at a constant feed flow rate which causes flow pattern changes inside the membrane where voids start to occupy more space than the liquid, thus resulting in permeate flux decrease.

Effect of Transmembrane Pressure on Total Permeate Flux

The effect of transmembrane pressure (TMP) on total permeate flux with gas sparging technique at a constant feed flow rate is given in *Figure 4*.

The transmembrane pressure is calculated as the average of the pressure value before and after the membrane module minus pressure of permeate. The applied transmembrane pressure was varied from 7.5 psig to 13 psig. These results show that the permeate fluxes increase approximately linearly with increase in transmembrane pressure and then decreases gradually.

Effect of the Feed Flow-rate on Total Permeate Flux

The effect of feed flow-rate at a constant flow rate of gas sparging (500 mL/min) on total permeate flux at different transmembrane pressure for 240 min is shown in *Figure 5*. The figure generally shows a linear increase in permeate flux with an increase in feed flow-rate. However there was a sudden sharp decrease at a feed flow-rate of 1600 mL/min. Decrease of the total permeate flux at a feed flow-rate of 1600 mL/min was probably due to reduction in the driving force acting on permeable solution causing the concentration of rejected solute on the membrane surface

being higher than that in the bulk solution. This is the so-called concentration polarisation phenomenon, which results in fouling and solute adsorption on the membrane as well as a flux decline. As a consequence, less solution can pass through the membrane and the rest remain as retentate. The figure also shows that the maximum permeate flux occurred at the feed flow-rate of 1400 mL/min.

Cake-layer Resistance

The effect of different flow rate of gas sparging on cake-layer resistance at a constant feed flow-rate and at transmembrane pressure of 13 psig for 240 min is shown in *Figure 6*. It shows that the increase in flow rate of gas sparging can reduce cake-layer resistance. Reduction of cake-layer resistance due to cake-layer formation on membrane surface is small. For non-gas sparging condition the cake-layer resistance is high. However when the gas is injected into the feed stream, it disrupts concentration polarisation and causes an increase in turbulence in the feed stream thus sweeping away foulant into the retentate. Images of cake-layer formation that were taken using scanning electron microscope (SEM) can be seen in *Figures 7a* and *7b*. From the images, cake layer (external fouling) that was formed on membrane surface under non-gas sparging condition was more distinct than under gas sparging condition. Development of cake layer on membrane surface with time increases with cake-layer resistances. Cake-layer resistance increases with time as the retained particles accumulate on and within in the membrane. Deposition and adsorption of small particles or macromolecules formed as internal fouling is usually irreversible. Flux decline in membrane filtration is a result of the increase of the membrane resistance due to the development of these additional resistances.

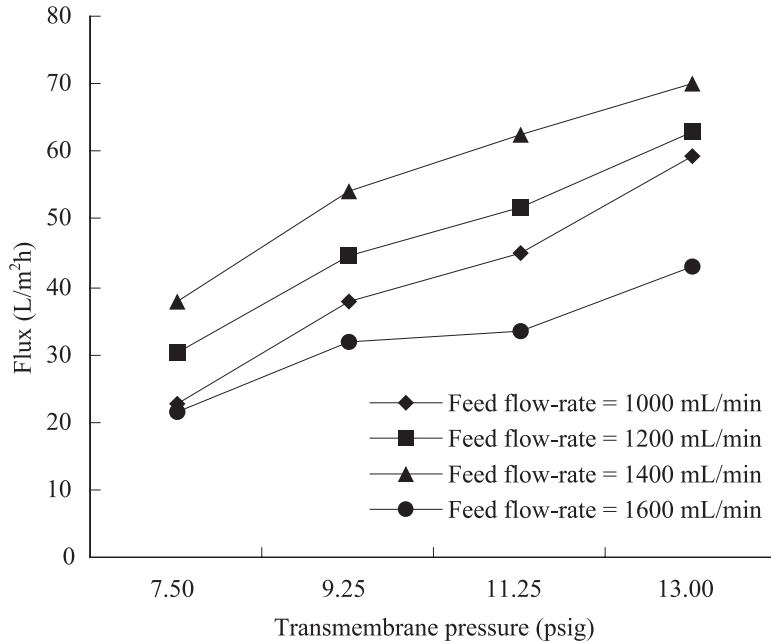


Figure 4. Effect of transmembrane pressure on permeate flux at feed flow-rate of 1400 mL/min for 240 min.

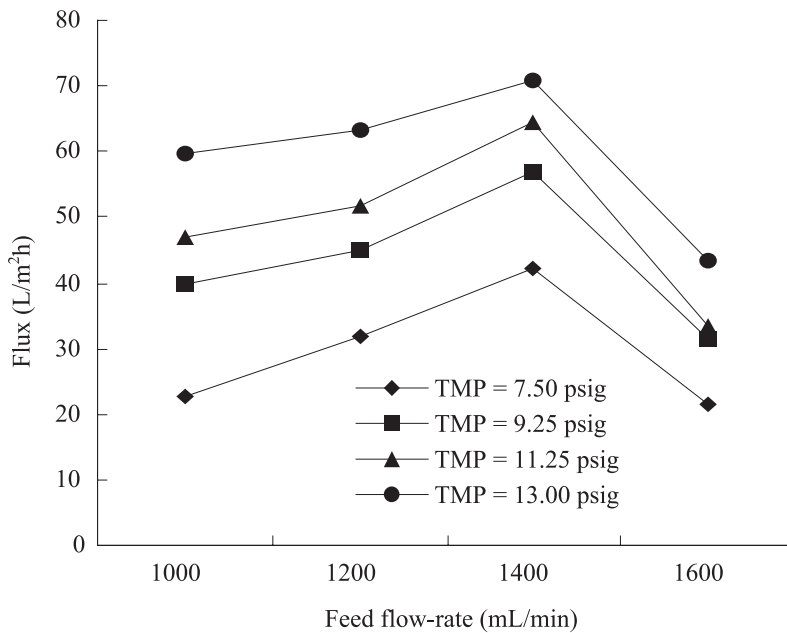


Figure 5. Effect of feed flow-rate on permeate flux under gas sparging condition at different transmembrane pressures for 240 min.

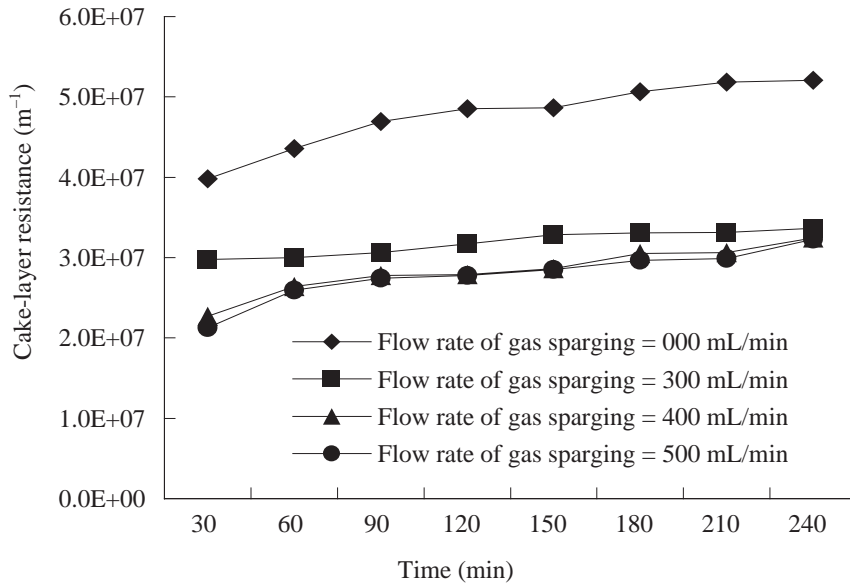


Figure 6. Effect of gas sparging on cake-layer resistances at feed flow-rate of 1400 mL/min and transmembrane pressure of 13 psig for 240 min.

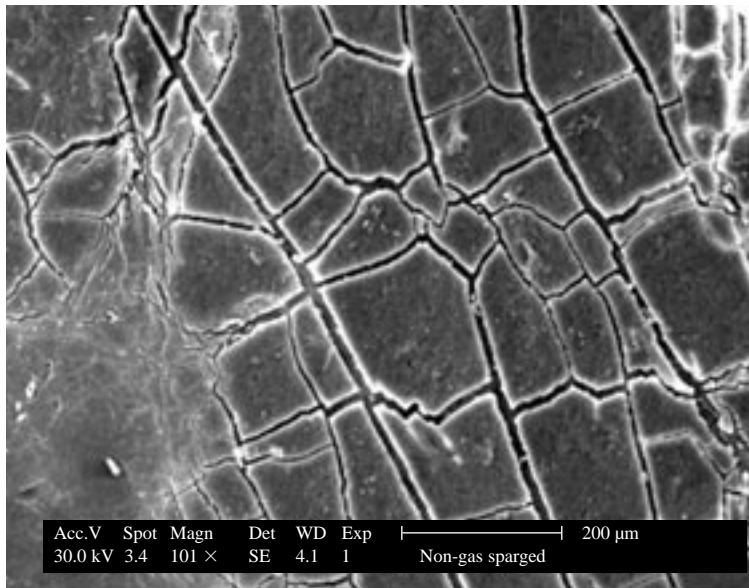


Figure 7a. SEM of external fouling on membrane surface after crossflow ultrafiltration of skim latex serum at feed flow-rate of 1400 mL/min and transmembrane pressure of 13 psig under non-gas sparging condition.

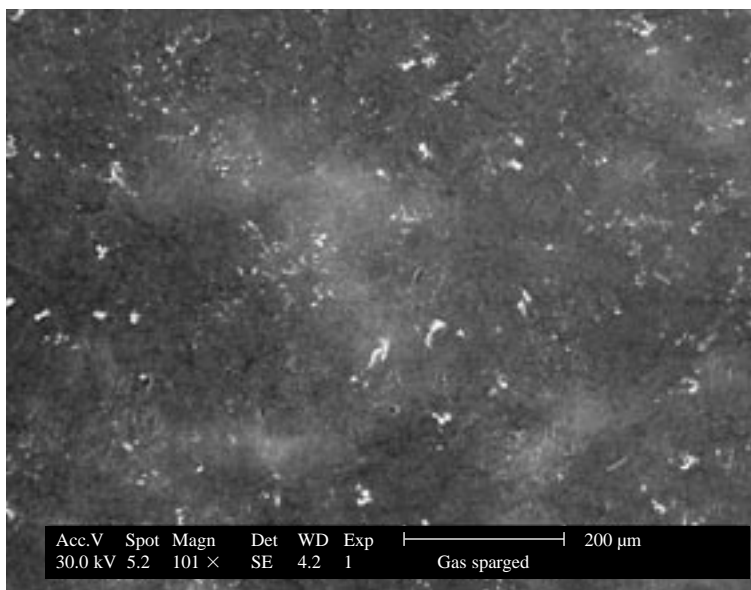


Figure 7b. SEM of external fouling on membrane after crossflow ultrafiltration of skim latex serum at feed flow-rate of 1400 mL/min and transmembrane pressure of 13 psig under gas sparging condition.

CONCLUSIONS

In this study, the potential of ultrafiltration using gas sparging technique on permeate flux of natural rubber processing effluent was investigated and the following conclusions could be drawn:

- Reductions achieved for permeate quality with gas injection technique for total solids, COD, BOD, total nitrogen and $\text{NH}_4\text{-N}$ were 95%, 67%, 77%, 51%, 74%, respectively.
- Reductions achieved for permeate quality non-gas injection technique for total solids, COD, BOD, total nitrogen and $\text{NH}_4\text{-N}$ were 96%, 67%, 72%, 60%, 75%, respectively.
- Using gas injection, the homogeneous liquid phase was changed to heterogeneous gas-liquid phase.
- The technique of gas injection into feed stream was found to be effective in enhancing permeate flux.
- Gas injection technique when compared with non-gas injection technique resulted in a permeate flux increase which ranged from 8.3% and 145.3%.
- In this study, the recommended conditions were 500 mL/min for gas injection, 1400 mL/min for feed flow-rate, and 13 psig for TMP.

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